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TEMPERATURE DATA ON MK 82 BOMBS USED IN CASS MINI-DECK TESTS

by

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ABSTRACT. Thermal characteristics were determined on inert Mk 82 bombs subjected to elevated temperatures during the CASS Mini-Deck Test Series Nos. 2 through 11. Theoretical cook-off predictions on the bombs were made on the assumptions that the bombs contained H-6 explosive and that the inside and outside surfaces were not insulated or protected in any manner.

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FOREWORD

The study described in this report was undertaken to assist the Project Engineering Branch of the Systems Development Department during their evaluation of flight-deck fire-fighting systems. This report deals with the thermal characteristics of inert Mk 82 bombs when subjected to elevated temperatures. The inert Mk 82 bombs were employed during the Carrier Aircraft Support Study (CASS) Mini-Deck Test Series Nos. 2 through 11 during the period 20-26 February 1970.

The CASS project was conducted under the sponsorship of the Naval Air Systems Command 007X, and is described in AirTask No. A303510A/216C/0W47-36-0000.

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NOMENCLATURE

A	Frequency factor, sec^{-1}
a	Radius, cm
c	Heat capacity, cal/g
$\frac{dT}{dt}$	Heating rate, °C/sec
DSC	Differential scanning calorimeter
E	Activation energy, kcal/mole
F	Function depending on geometry and the initial temperature
k	Specific rate constant, sec^{-1}
Q	Heat of reaction, cal/g
R	Gas constant, 1.987 cal/mole-°K
T	Absolute temperature, °K
t	Time, seconds
T_1	Surface temperature, °K
t_e	Time to exotherm or deflagration, sec
T_m	Critical temperature, °K
α	Thermal diffusivity, cm^2/sec
ϕ	Constant heating rate, °C/min
λ	Thermal conductivity, cal/cm-sec-°K
∇	Laplacian operator
ρ	Density, g/cm^3
δ	Shape factor
τ	Dimensionless time

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INTRODUCTION

Several serious fires aboard aircraft carriers have focused attention on the need for intensified research and development in fire-fighting technology and the effects of fires on ordnance items carried aboard attack aircraft. Although the explosives can create a very hazardous situation when they are subjected to elevated temperatures, the hazard may be partially mitigated if existing ordnance items could be modified so that additional fire-fighting time would be made available. This would allow the fire fighters to cool the heated ordnance items so that runaway decomposition reactions would not set in, allowing sufficient time for the disposal team to jettison the items over the side.

Studies on lengthening the cook-off time of different ordnance items are reported in Ref. 1 through 5. To help evaluate the present state of affairs, the Carrier Aircraft Support Study (CASS) Mini-Deck Test Series was run to provide information on the effectiveness of different fire-fighting techniques and on the thermal characteristics of the ordnance items when subjected to elevated temperatures.

This report confines itself mainly to the behavior of the ordnance items at elevated temperatures and only incidentally to the effectiveness of the fire-fighting techniques.

INSTRUMENTATION AND EQUIPMENT SET-UP

On a typical aircraft hangar or flight deck, fire-fighting is often hampered by airplanes, vehicles, and equipment. Smoke, heat, and toxic fumes from a fire can readily make a hangar or flight deck untenable and may necessitate the evacuation of personnel. Therefore, it would be necessary to rely on fixed monitors or sprinkler systems. The monitors and sprinklers provide only limited coverage due to obstructions such as aircraft wings and radar domes in the path of the fire-suppressant material. The CASS Mini-Deck was constructed to provide a simulated flight deck where methods for evaluating personnel safety (cook-off of bombs), fire-fighting systems, etc., could be tried. A schematic layout of the CASS Mini-Deck fire-fighting test bed is shown in Fig. 1.

During the test series several methods of delivering fire-fighting agents were tested, such as flush-deck nozzles, deck-edge nozzles, monitors, and vehicles with articulated booms. In addition, various kinds of fire-fighting agents were compared and evaluated. A list of the various methods utilized for applying the fire-suppressant material is given in Table 1. The fire-suppressant agent used in these tests was known as aqueous film-forming foam (AFFF).

TABLE 1. Application of Fire-Suppressant Agent.

Test No.	Primary method of application		Secondary method of application
	Technique (nozzles)	Flow rate	Technique
2	Flush deck	0.04 gpm/sq. ft.	Hand lines
3	Flush deck	0.06 gpm/sq. ft.	Hand lines
4	Flush deck Monitor (PC-50 aerating)	0.04 gpm/sq. ft. 500 gpm	---
5	Monitor (PC-50 aerating)	458 gpm	Hand lines
6	Monitor (PC-50 aerating)	458 gpm	---
7	Flush deck	0.04 gpm/sq. ft.	Hand lines
8	Monitor (1 1/2" solid stream)	730 gpm	---
9	Monitor (1 1/2" solid stream)	700 gpm	---
10	Monitor (1 1/2" solid stream)	730 gpm	Hand lines
11	Flush deck	0.06 gpm/sq. ft.	Hand lines

NOTE: One bomb under each wing for Tests 2-7,
Two bombs under each wing for Tests 8-11.
Neat water was used for Test No. 8; AFFF was the agent used for all other tests.

A total of 26 test runs were carried out during the fire-fighting evaluation program. However, only 10 tests (Test No. 2 to 11) utilized instrumented inert Mk 82 bombs, and the results are presented in this report.

Selected areas of actual flight-deck conditions were simulated by the use of a steel-covered deck (36 x 64 1/2 feet) and the adjoining concrete apron (15 x 64 1/2 feet). One metal mockup airplane was utilized, having a total capacity of four bombs. There were no obstructions such as additional aircraft and ground-handling vehicles. Since the deck simulated only part of an actual flight-deck, it was necessary to curtail many aspects that would be representative of an actual operational configuration. However, the tests did provide some valuable insights, and provided training and comprehension of the many problems involved, making it possible to effectively plan for larger and more realistic testing operations.

The Mk 82 bomb was used during the tests as this bomb is commonly used in current areas of operation. The bomb casings were the regular production-type and were not totally insulated on the interior or protected on the exterior in any special manner. They had a partial inner layer of hot melt so that a limited evaluation of the liner material could be made.

The thermocouple probes were made of 24-gauge type-K (chromel-alumel) thermocouple wire for the internal locations, and of 20-gauge type-K wire for the two external probes. The locations of the thermocouple probes for the port bombs are shown in Fig. 2, and for the starboard bombs in Fig. 3. All but four thermocouple sensors were spot-welded at various locations on the inside of the bomb case. The four were positioned as follows: for the bottom outside skin temperature, a hole was drilled through the skin so that a 2-hole ceramic tube could be inserted. The wire was fed through the ceramic, beaded, and then welded onto the outside surface, and a piece of nichrome ribbon was welded over the bead for protection. A second hole was drilled in the side of the bomb so that a thermocouple tip could be extended 1/2 inch outside the bomb to record the flame temperature. Only one thermocouple was employed to record the flame temperature adjacent to the bomb, since there were only a limited number of thermocouples available for each bomb and it was desirable to obtain a broad coverage of data sources. A third thermocouple probe was positioned at the center of the bomb, and the fourth (TC 5) was later placed on top of the hot melt. In preparation for TC 5, a standard hot-melt liner material was poured into the bottom concave portion of the bomb, with the bomb being in the same attitude as when hung onto the bomb rack. The liner did not cover the sides, top, or extreme bottom areas of the bomb; it was concentrated in the area where the majority of the thermocouples were attached. After the liner material had cooled, the sensing part (1/2- x 1/2-inch metal tab) of TC 5 was placed on top of the 1/2-inch layer of hot melt.

After the bombs were thermocoupled and partially lined with the hot melt, they were filled with clean dry sand. Sand was used as a filler since its thermal diffusivity (α) is similar to that of the H-6 explosive. It was determined that the value of α for the H-6 explosive was 0.0024 cm^2/sec; it was 0.0034 cm^2/sec for clean dry sand. Also, dry sand was used for safety considerations. For example, it was not advisable to utilize any material that contained moisture in any form, i.e., surface water or water of hydration. It would be possible for a bomb case to rupture if the filler material contained a sufficient amount of water, the casing had a weak weld, and the bomb was subjected to intensive rapid heating; the metal fragments could possibly cause injury to nearby firefighters.

The inert bombs were attached to racks welded to the underside of the wing of the metal mockup aircraft. The bomb racks were fabricated of heavy sheet metal in the form of a wide "V", with provisions to secure

two bombs on each rack, one bomb on the outboard side and one on the tip of the V. There was one rack on each side of the airplane. For tests No. 2 through 7, one Mk 82 bomb was attached under each wing, and for tests No. 8 through 11, two Mk 82 bombs were attached under each wing. When only one bomb was attached to the rack, it was placed on the tip of the V. The upper bomb was 3 feet above the test deck and the lower bomb was 2 feet above the deck. There were no problems with the bombs and the bomb racks during the test series.

The thermocouple lead wires were never exposed directly to the flame. All of the thermocouple leads came from the interior of the bomb via a small section of metal pipe that ran from the top of the bomb to a metal box welded within the V of the bomb rack. From this metal box, the wires ran through a rigid 2-inch-diameter metal conduit pipe that extended horizontally and then vertically downward to a metal thermocouple junction box in the test deck. A pipe ran underground from the junction box to the control building, where the temperature data were recorded. Lagging (85% MgO and 15% asbestos) was used to insulate the conduit piping from the thermocouple junction box to the bomb. The outside of the metal box in the bomb rack was not insulated, but the inside contained dry Eagle 66 cement. The insulation was very effective and the thermocouple lead wires were never damaged by heat during the entire test series.

The temperature data from the bombs on the port wing were recorded on a portable temperature-data acquisition system; the scanning speed was ten thermocouples five times a second. The data for the bombs on the starboard wing were recorded with a multipoint strip-chart recorder which had a scanning speed of about 1 second per point; this recorder could handle a maximum number of 24 points.

The prop wash of a stationary C-97 aircraft was employed to simulate the critical wind factor (30-35 knots), and JP-5 jet fuel was burned to provide the heat source for the tests.

EXPERIMENTAL DATA

Because the size of the test deck represented just a portion of an actual flight deck, only one mockup aircraft was used. This condition exaggerated the wind effect, since there were no nearby aircraft to provide a buffering and a sheltering effect for the test items. The mockup aircraft was positioned on the Mini-Deck in such a manner that the bombs located on the port wing received the wind from the C-97 (wind generator) and the fire-suppressant material directly, while the bombs located on the starboard wing were somewhat protected by the fuselage of the mockup aircraft. Therefore the sheltered bombs normally received more heat from the fire for a longer time period than those on the windward side. The

ambient wind condition during a test run also affected the test data. When the ambient wind direction was directly opposed to that generated by the C-97 a strong whirlwind effect was created. This effect was readily apparent in Test No. 2 and to a minor degree in Test No. 7, in which there were a series of minor whirlwinds.

The temperature profiles[1] from the port bombs during Test Nos. 2-11 are given in Fig. 4-23, which includes the profiles on the flames and on the inside and outside bottom skin of the bomb casing. The profile of TC 5 (top of hot melt) during Test No. 2 was included in Fig. 5. Data obtained from TC 7, at the inside bottom skin of the bomb, was used to note the maximum temperature attained and to calculate the rate of heating at the inside surface of the bomb. The profiles from TC 3 (outside surface) served as a check on the internal skin temperature values. Only a limited number (approximately one-third) of the thermal profiles on the port bombs are reported. These are assumed to be of immediate importance and interest. However, since the additional curves may be of use, a listing of all available thermal profiles is given in Table 2. Copies of the profiles are available at the Naval Weapons Center (NWC), China Lake, California.[2] The numerical data used for the mechanical plotting of the profiles is available also. The time increment between the temperature points is 0.5 second.

All temperature profiles obtained from the starboard bombs during Test Nos. 2-11 are given in Fig. 24-33. The temperature values were gathered via the multipoint recorder. The data on the charts were reduced and the curves then were plotted by hand.

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[1]In this report, the temperature-time graphs were plotted to various units per given space instead of to a common uniform scale. The data from the port bombs were plotted automatically by the data-acquisition system, which adjusted the vertical and horizontal scales so that the available data would give full coverage within a standard-size format. For the graphs on the starboard bombs, the temperature increments per given space were identical but the time scale was adjusted so that the available data would give approximately full coverage within a standard-size sheet of graph paper.

[2]Project: Naval Weapons Center CASS Test Series AIR-007XD of 20-26 February 1970.

TABLE 2. Temperature Profiles Obtained From Port Mk 82 Bombs.

Test No.	Thermocouple (TC) No.								
	1	2	3	4	5	6	7	8	9
2	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X	X	X
6	X	X	X	X	X	X	X	X	X
7	X	X	X	X	X	X	X	X	X
8	X,0	X,0	X,0	X	0		X		X
9	X,0	X,0	X,0	X	0		X		X
10	X,0	X,0	X,0	X	0		X		X
11	X,0	X,0	X,0	X	0		X		X

NOTE: X = Bomb on bottom of bomb rack
0 = Bomb on side of bomb rack
Location of thermocouples:

TC	Location
1	Nose, inside
2	Skin, bottom, inside
3	Skin, bottom, outside
4	Ring, bottom, inside
5	Hot melt, top
6	Sand, center
7	Skin, bottom, inside
8	Ring, bottom, inside
9	Flame

A temperature-difference relationship between the outside and inside skin temperature probes (TC 3 and 2) for the starboard bombs was apparent during the test series. From Tests 2 through 6, the outside skin temperatures were always higher than the inside skin temperatures. However, for Tests 7 through 11, this relationship persisted only to about the 75- to 90-second mark, when there was a crossover and the inside skin temperatures became greater than the outside skin temperatures. An examination of the original records did not reveal any conspicuous reasons for these relationships. However, a rational approach would consider a number of factors which may be inherent in the limitations imposed by the conditions of the test. Some of the factors are: (1) the recorded temperature is indicative only for the tip of the probe, not for a large skin area, (2) the probe tips are spaced apart from each other, (3) any localized hot or cold areas, due to uneven application of fire-suppressant agent or sporadic changes in flame temperature, may not be sensed evenly by both thermocouples, and (4) the number of available thermocouples was limited so that redundancy could not be employed advantageously.

An examination of the flame- and skin-temperature profiles indicates that the inside skin temperature does not decrease as soon as the external heat source (flame) is reduced or extinguished. The inside temperature will remain constant or it will continue to increase for an additional time. And if the explosive in a bomb, for example, is heated beyond its critical temperature, the explosive material will eventually cook off. In many of the tests the bombs were subjected to a low flame profile, which was especially noticeable for the bombs on the port wing, which were subjected to the windward effects. This was apparent when the data for the maximum temperature values were examined (Table 3).

The initial spike on most of the flame-temperature profiles was caused by the off-on phenomenon associated with the operation of the wind generator. Although the engines were running at fuel ignition, they were throttled down to minimum idling speed and the propellors were generally in reverse pitch. Therefore, the prop wash was not actively directed towards the fire. This allowed the flames to have a good vertical development early in the burn. Then, when the engines were accelerated, the prop wash was activated in the direction of the test deck. This caused the flame envelope to be lowered and consequently the heat was directed toward a more horizontal flow pattern, with overall lower flame-temperature values at the point of measurement. The foregoing comments are particularly applicable to the port bombs. Typical examples for the port bomb are illustrated in Fig. 12 and 14. For the starboard bombs, the flame temperature usually continued to rise after the initial spike because the bombs were shielded and protected by the fuselage of the mockup aircraft. Typical examples for the starboard bomb are given in Fig. 26 and 31.

TABLE 3. Maximum Temperatures of Flame and Bomb Skin.

Test No.	Maximum temperature, °C[a]					
	Flame		Outside skin		Inside skin	
	Port	Starboard	Port	Starboard	Port	Starboard
2	559	b	396	372	389	207
3	126	608	174	429	166	192
4	343	650	191	360	179	152
5	203	605	146	202	127	95
6	125	c	132	c	118	82
7	177	572	153	345	149	390
8	170	480	128	120	111	125
9	161	673	122	212	111	165
10	221	685	133	212	120	180
11	210	551	137	187	123	195

[a]Source of data:

Area	Mk 82 bomb	
	Port	Starboard
Flame	TC 9	TC 6
Outside skin	TC 3	TC 3
Inside skin	TC 7	TC 2

[b]Data off scale.

[c]Data missing - mechanical problem in recorder.

ANALYSIS OF EXPERIMENTAL DATA

Two methods were used to estimate the time to cook-off. The first method involved a simple constant-heating rate. This method is only an approximation and cannot be applied in every case; it can be used only where the ignition of the H-6 explosive occurred at some specific heating rate at the inside surface of the bomb. A plot of thermal analysis data on H-6 explosive is shown in Fig. 34. This plot does not consider mass effect, which should be small at the high heating rates. The temperature data is for the explosive in contact with a metal. The temperature at a given heating rate would be lower for an explosive in contact with an insulating material. The insulating material would also affect the heating rate. For example, Test No. 7 (Fig. 29) shows a heating rate of 2.78°C per second at the inside surface of the starboard bomb, which should give a cook-off time of about 2.2 minutes for a temperature of 287°C (from Fig. 34 and 29).

The second method considered the following general heat-flow equation

$$-\lambda \nabla^2 T + \rho c \left(\frac{\partial T}{\partial t}\right) = \rho\, QAE^{-E/RT}, \tag{1}$$

where the first term, $-\lambda \nabla^2 T$ involves the temperature profile within the explosive, which is dependent on the transfer of heat from the mass. The second term involves the heating rate and the third term involves the heat generated by chemical action. For an adiabatic situation, which is described as a no-heat-transfer condition from the center of the explosive charge to some other point in the charge, Eq. 1 then reduces to

$$k = \frac{c}{Q}\left(\frac{dT}{dt}\right) \tag{2}$$

when $-\lambda \nabla^2 T$ equals zero. Under steady-state conditions where $\rho c\ (\partial T/\partial t)$ equals zero, the heat balance can be calculated as the critical temperature, T_m, in Eq. 3

$$T_m = \frac{E}{2.303R \log\left(\dfrac{\rho a^2\ QAE}{\lambda RT^2\ \delta}\right)} \tag{3}$$

When the surface temperature (T_1) exceeds T_m under steady-state conditions and a zero-order reaction model is considered, the time to deflagration, t_e, is given by

$$\frac{t_e \lambda}{\rho \, ca^2} = F \left(\frac{E}{T_m} - \frac{E}{T_1}\right) , \tag{4}$$

where the dimensionless time t_e/τ (first term reduced) is a function of $(E/T_m - E/T_1)$.

For reduced time, τ,

$$\tau = \frac{a^2}{\alpha} = \frac{\rho ca^2}{\lambda} \text{ , where } (\alpha = \frac{\lambda}{\rho c}) \tag{5}$$

From a plot of Eq. 4 a value of X (Ref. 6) can be found in

$$\frac{1}{T_m} = \frac{1}{T_1} + \frac{X}{E} \tag{6}$$

for some ratio of

$$\frac{t_e}{\tau} , \tag{7}$$

thereby calculating the time to cook-off, t_e from data in Eq. 6. A more complete treatment on reaction kinectics is given in Ref. 7.

The first method was used in calculating the time to cook-off for Tests No. 2 (port bomb) and No. 7 (starboard bomb). The heating rate for Test No. 2 was 3.55°C per sec from 88 to 255°C at the inside skin temperature (TC 7 of Fig. 5). Using the plot in Fig. 34, this would have resulted in an "ignition" at 292°C for Test No. 2. At this temperature, a cook-off would have occurred 2.7 minutes from time zero of Fig. 5. The heating rate at the inside skin of Test No. 7 was 2.78°C per sec (100-200°C region for TC 2 in Fig. 29). At this heating rate, the "ignition" temperature would be 287°C (Fig. 34). Cook-off would have occurred 2.2 minutes after time zero in Fig. 29.

A critical temperature of 143°C was predicted on the H-6 explosive from Eq. 3 and the following experimental data on H-6 explosive and the Mk 82 bomb, where

δ = 2.00

ρ = 1.75 g/cm^2

a = 12.5 cm radius (9.8 in. dia.)

Q = 321 cal/gram

R = 1.987 cal/mole-°K (gas constant)

λ = 0.0011 cal/cm-sec-°C

E = 51.4 kcal/mole

A = 1.56 x 10^{20}/sec

The second method was used to determine the cook-off times for the remaining bombs. Equations 4, 5, and 6, and the critical temperature value determined from Eq. 3, were used to predict the time to cook-off of a Mk 82 bomb versus surface temperature of the explosive (Fig. 35). The predicted cook-off times for both methods are listed in Table 4, and the cook-off possibilities are summarized in Table 5. The temperature would have been much higher at the interface between an explosive and the steel surface because of the exothermic action of the explosive. These exotherms can run to 100°C, or much more, above the temperature of the inside surface.

All calculations and determinations were based on the premises that the Mk 82 bomb casings were the regular production-type and were not insulated or protected in any special manner. All predictions were based on the bottom inside skin temperature values and on the assumption that the bombs contained H-6 explosive. It was assumed that the bottom portion of the bomb received the greatest influx of heat from the burning fuel on the test deck. An inner liner of hot melt, for example, could extend the time to cook-off for an additional 2 minutes or more. However, for this study, the worst possible set of circumstances were assumed, e.g., no inner liner at all, or a liner with some voids which would place the explosive directly in contact with the inner skin, and no protective coating on the exterior surface of the bomb.

When a time to cook-off is given for a definite temperature value, the explosive must remain at the specified temperature for the given time to accomplish the predicted result. If the temperature decreases sufficiently during the time period, it is possible that the explosive will not cook off. One very important factor to consider is the time to cook-off. Longer times to cook-off are usually associated with a more violent reaction. During experimental field testing of H-6 explosive in small-scale (2-pounds) bomb tests and in standard Mk 82 bombs,

TABLE 4. Calculated Times to Cook-off.

Test No.	Port bomb[a]		Starboard bomb[a]	
	Time, min	Temperature, °C[b]	Time, min	Temperature, °C[b]
2	2.7	292	17	207
3	NCO[c]	166 max	75	192 max
4	225	179 max	NCO	152 max
5	NCO	127 max	NCO	95 max
6	NCO	118 max	NCO	82 max
7	NCO	149 max	2.2	287
8	NCO	111 max	NCO	125 max
9	NCO	111 max	NCO	165 max
10	NCO	120 max	210	180 max
11	NCO	123 max	54	195 max

[a]Source of data:
Port bomb TC 7
Starboard bomb TC 2

[b]Temperatures at inside surface of bomb.

[c]NCO = no cook-off.

TABLE 5. Cook-off Possibilities for Mk 82 Bombs.

Action	Test No.	Position	
		Port	Starboard
Definite cook-off	2	X	X
	7		X
Potential cook-off	3		X
	11		X
No cook-off	3	X	
	4	X	X
	5	X	X
	6	X	X
	7	X	
	8	X	X
	9	X	X
	10	X	X
	11	X	

it was observed that as the induction time became longer, from application of heat to cook-off, there was usually a corresponding increase in the severity of the reaction, i.e., from deflagration to explosion to detonation.

The effectiveness of a liner material as an insulating barrier was evaluated during the tests. Although the results may be grossly exaggerated because of an excess amount of material (1/2-inch thickness instead of the usual 1/4-inch or less thickness), it may be noteworthy to examine the accumulated data. Figure 5 illustrates the insulating properties of the hot melt during the first exposure of the port bomb to heat (Test No. 2). The top surface of the liner was relatively unaffected for 272 seconds (4 1/2 minutes); during this period, the temperature at the top surface of the liner was maintained at 13-15°C. In contrast to this long induction period, the temperature at the bottom inside skin (TC 7) started to rise slowly at about 45 seconds and then accelerated after 65 seconds. During the next run (Test No. 3), the liner was effective for approximately 132 seconds (~2 minutes). In subsequent tests (Nos. 4 through 7), the liner material was effective for only 72-82 seconds. During Test No. 2 on the starboard bomb, the liner material was effective for at least 300 seconds (5 minutes). No data was obtained from TC 5 in the starboard bomb from Test Nos. 3 through 6. During Test No. 7, the liner was effective for only 85-90 seconds. These tests indicated that during or after the first hot run, the thermocouple tab had slowly sunk beneath the top surface of the hot-melt liner or the liner had melted or decomposed from the heat.

The effect of any residual heat in a bomb from prior tests was examined. During the test series, there were two days when the same bomb was subjected to four heat exposures per day. These were Test Nos. 3-6 on 24 February and Test Nos. 8-11 on 26 February. The printout data, from the data-acquisition system on the inside skin temperature for the port bomb, was examined for residual heat effect from prior tests. There was a 21-28°C increase in the initial temperature between the first test of the day and those run in the latter part of the day. There doesn't seem to be any real significance attached to this initial temperature differential. The limited number of tests indicated that the maximum inside skin temperature was more dependent upon the extent and duration of the external heat source. The effect on the starboard bomb could not be evaluated as critically because the data were recorded differently. However, it was noted that the maximum inside skin temperature was generally dependent on the intensity and duration of the external heat source.

A study was made on the relationship between (1) the amount of time the bomb was preheated before the fire-suppressant agent was turned on and (2) the temperature reached at the bottom inside skin of the bomb. The preheat time periods were measured on the graphs from the moment the flame envelope exhibited its initial vertical development to

the time when the agent was first applied. A plot was made of the preheat time versus the maximum inside skin temperature. The data from the port and starboard bombs were plotted on the same graph (Fig. 36). The limited data, plus the presence of many variables, gave a rather broad envelope of relationships. In general, there was a direct relationship between the preheat time and the maximum inside skin temperature. For example, the inside skin temperature ranged between 85 and 165°C for a preheat time of 25-40 seconds and between 130 and 195°C for a preheat time of 50-80 seconds. These preheat-time/inside-skin-temperature relationships can be easily altered, e.g., the heating rate can be changed drastically by the amount of fire-suppressant agent applied to the bomb during a critical period of time or by the presence of a strong or minor whirlwind as experienced during Tests 2 and 7.

CONCLUSIONS

During the first CASS test series, it was usually the starboard bomb which had definite or potential cook-off possibilities; the port bomb was a candidate only once, when the mockup aircraft was engulfed within a strong whirlwind effect. Because the starboard bomb was usually on the downwind side, it was protected by the fuselage of the mockup aircraft. This subjected the bomb to higher flame temperatures and longer exposures to the flames than that experienced by the port bomb.

When the cook-off possibilities were either definite or potential, the deck nozzles had been used to deliver the fire-suppressant material. When the monitors were used, the bombs were not listed as candidates for possible cook-off. Evidently, under the given test conditions, the monitors were able to deliver more effectively the fire-suppressant material in a shorter time period than the deck nozzles.

It is possible to predict the cook-off characteristics of a bomb that is subjected to an elevated external heat source. This determination will enable the firefighters to evaluate the effectiveness of their techniques, the cooling capacity of the fire suppressant agent, and the efficiency of the fire-fighting equipment.

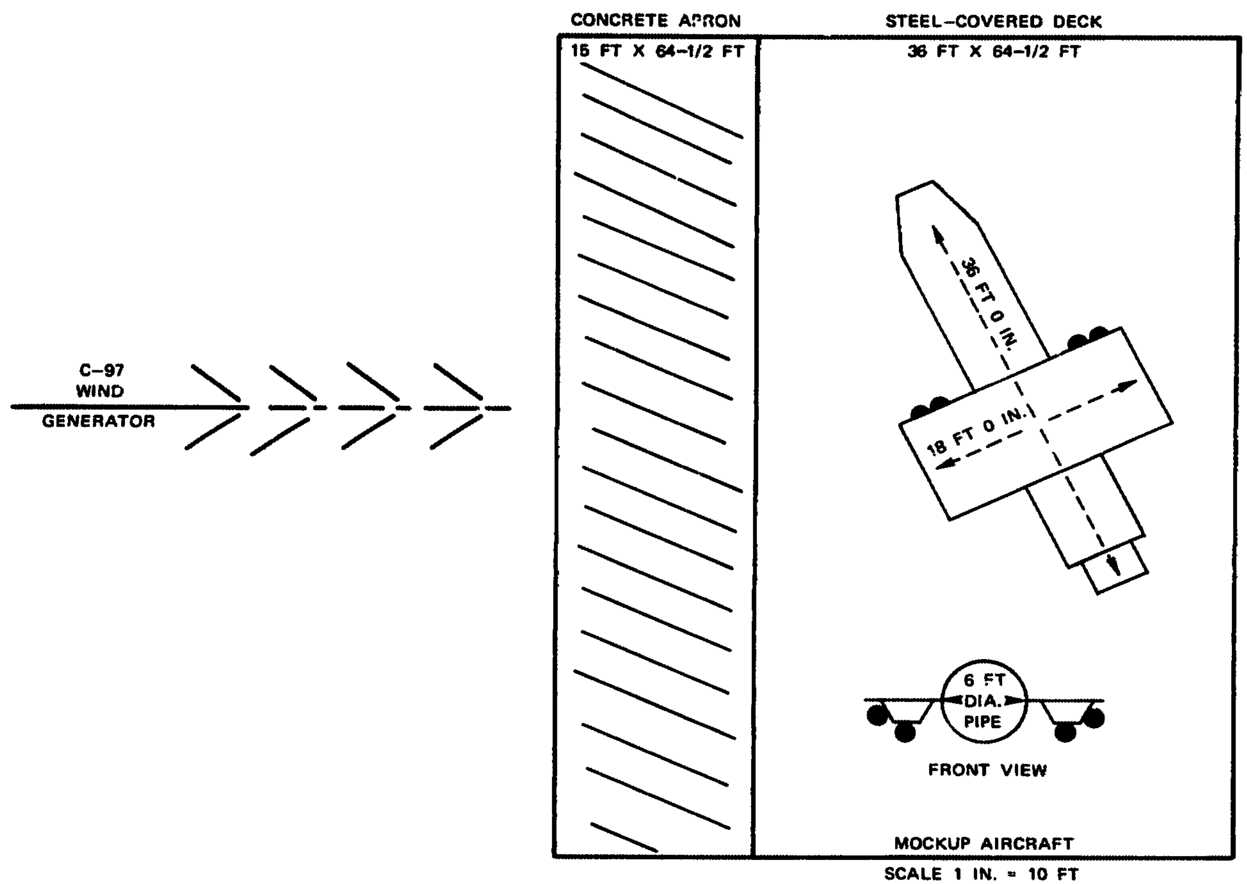

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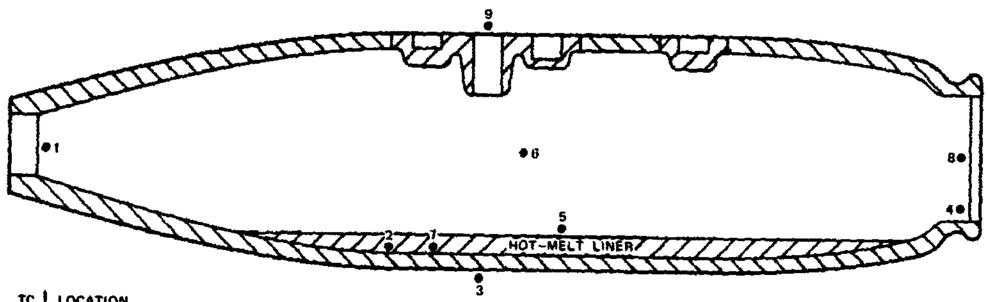
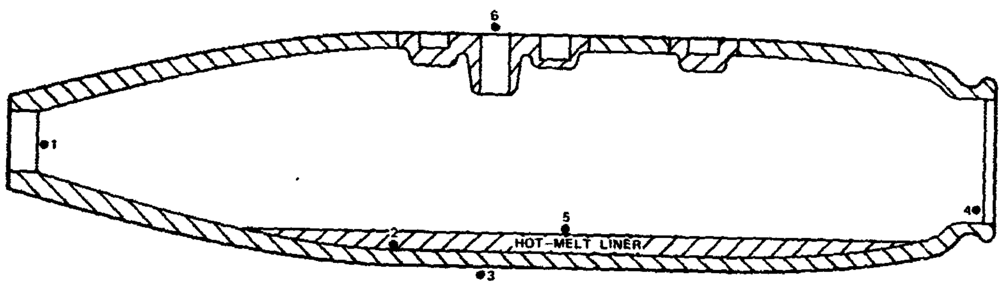
FIG. 1. Schematic Diagram of CASS Mini-Deck Fire-Fighting Test Bed.



TC	LOCATION
1	NOSE, INSIDE
2	SKIN, BOTTOM, INSIDE
3	SKIN, BOTTOM, OUTSIDE
4	RING, BOTTOM, INSIDE
5	HOT MELT, TOP
6	SAND, CENTER
7	SKIN, BOTTOM, INSIDE
8	RING, BOTTOM, INSIDE
9	FLAME

LHL 151751

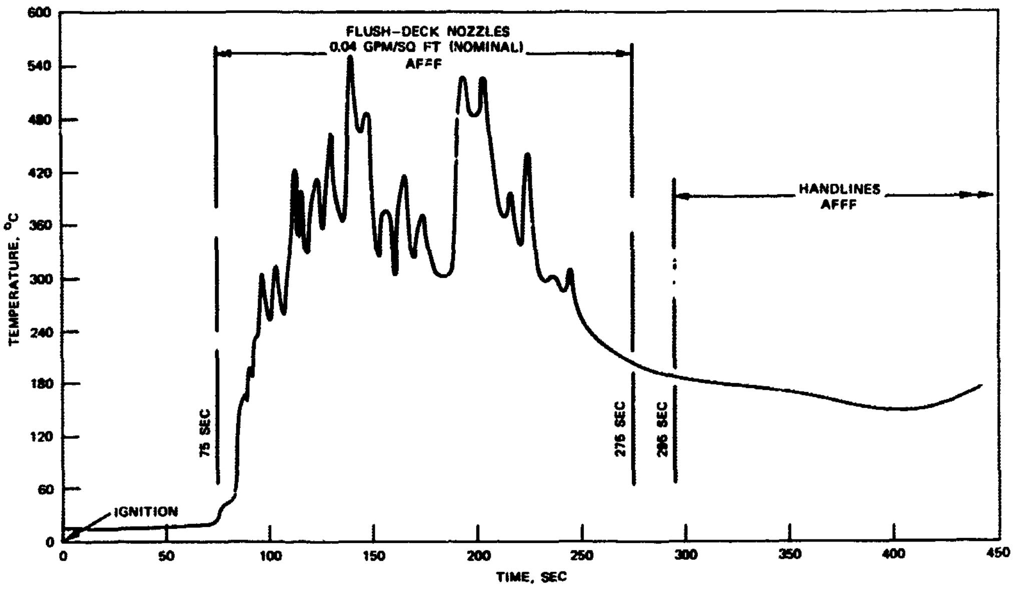
FIG. 2. Location of Thermocouples (TC) on Port Mk 82 Bomb. Data-acquisition system.



TC	LOCATION
1	NOSE, INSIDE
2	SKIN, BOTTOM INSIDE
3	SKIN, BOTTOM, OUTSIDE
4	RING, BOTTOM, INSIDE
5	HOT MELT, TOP
6	FLAME

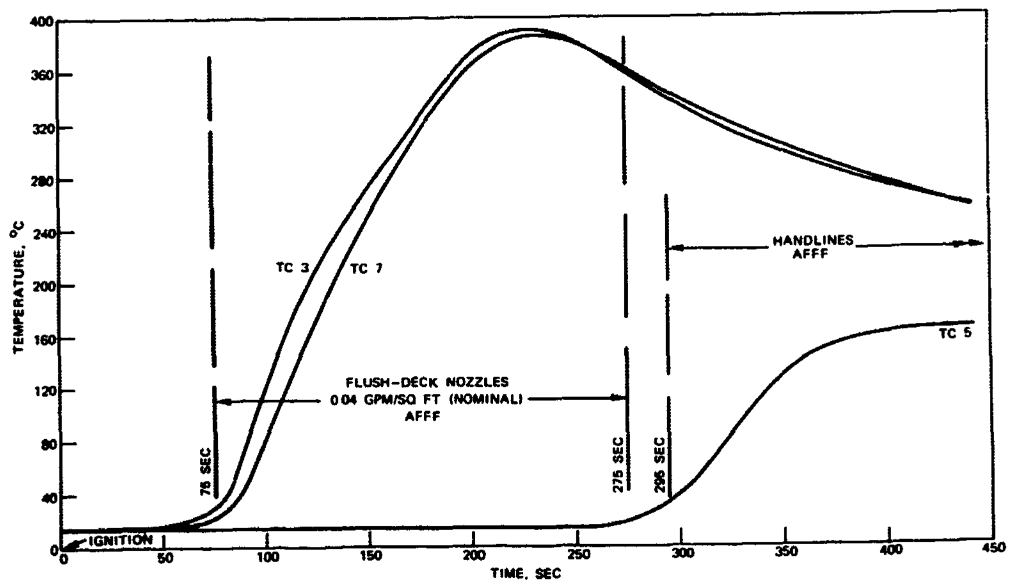
LHL 151752

FIG. 3. Location of Thermocouples (TC) on Starboard Mk 82 Bomb. Multipoint recorder.



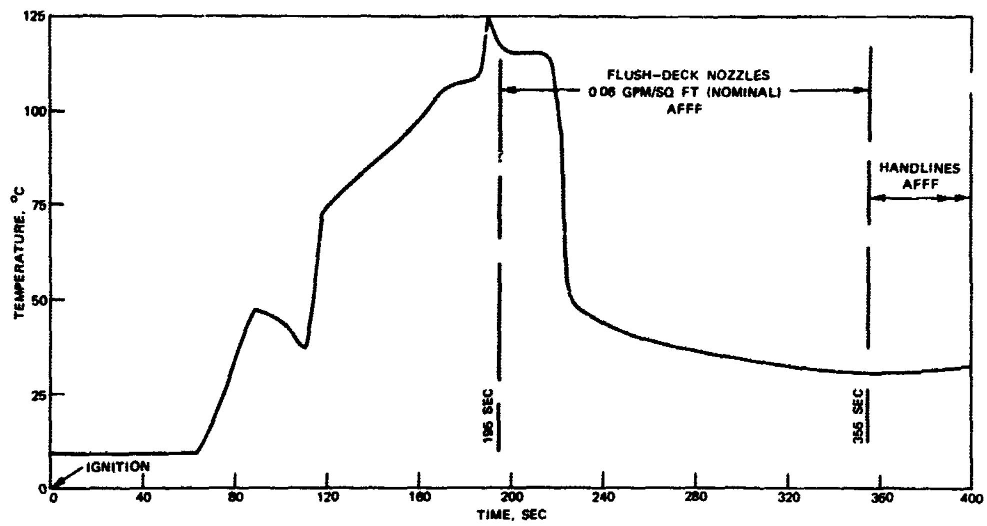
LHL 151753

FIG. 4. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 2.



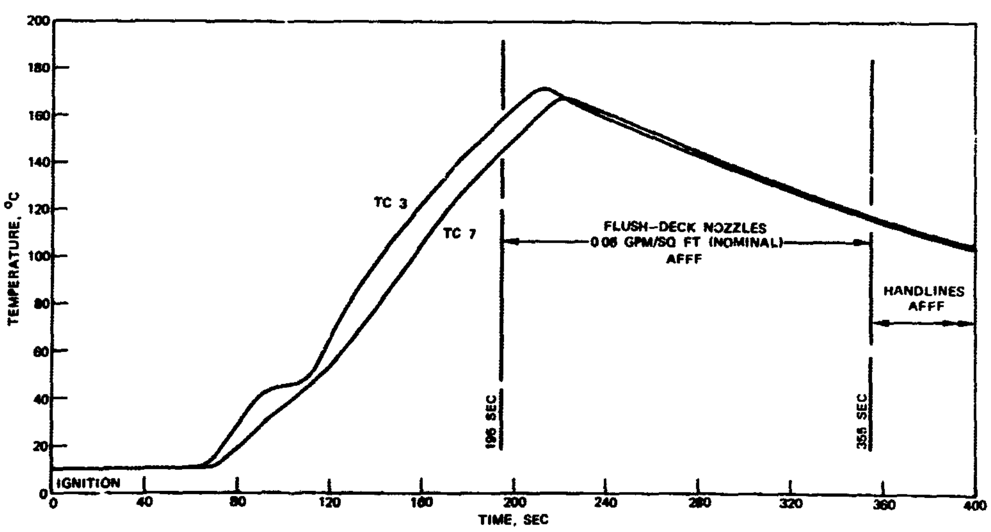
LHL 151754

FIG. 5. Temperature Profiles of TC 3, 7, and 5 for Port Mk 82 Bomb During Test No. 2.



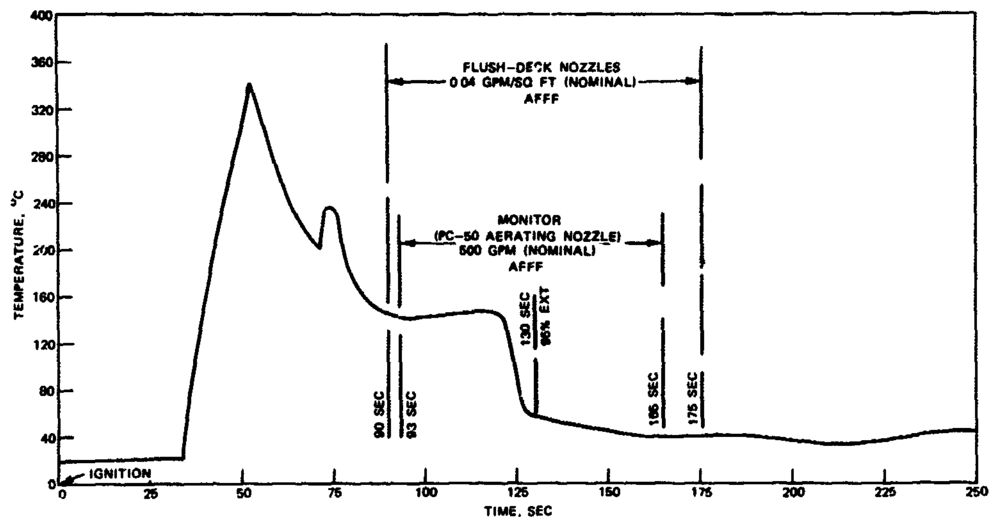
LHL 151755

FIG. 6. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 3.



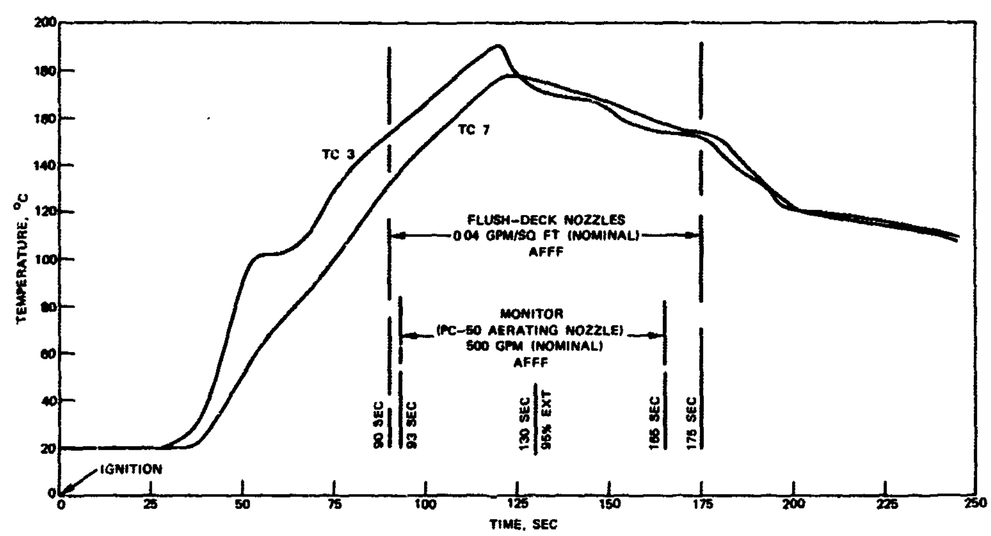
LHL 151756

FIG. 7. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 3.



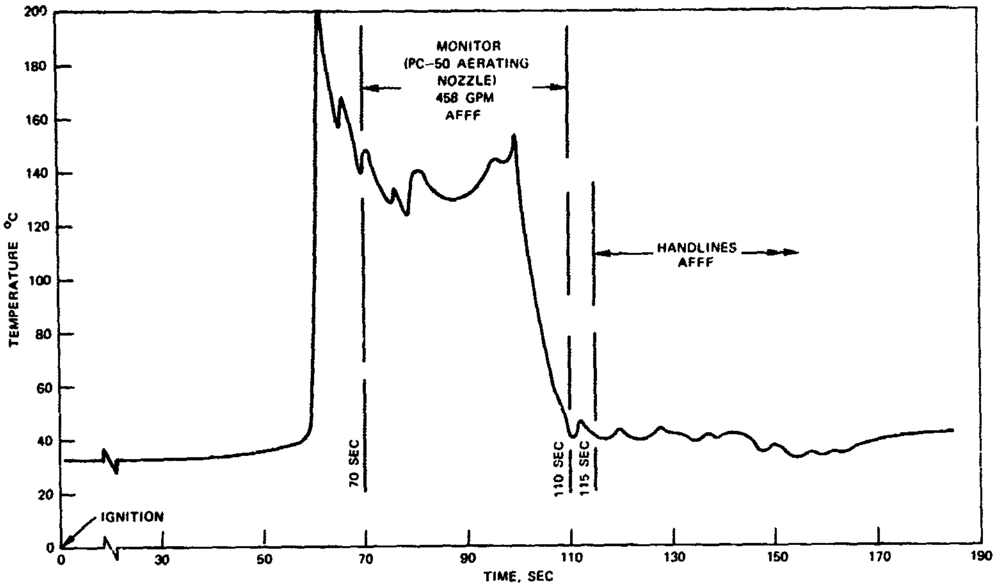
LHL 151757

FIG. 8. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 4.



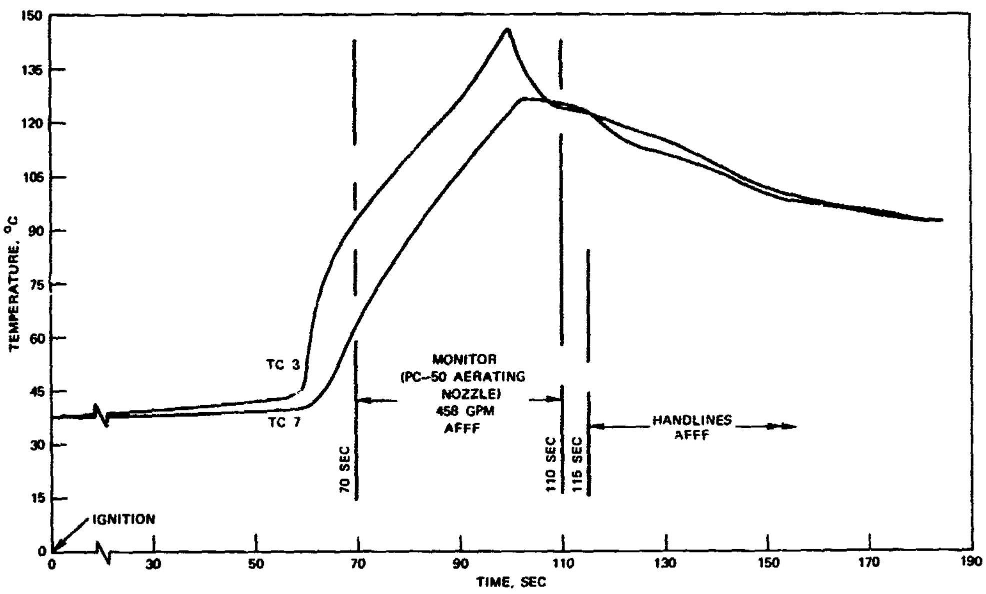
LHL 151758

FIG. 9. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 4.



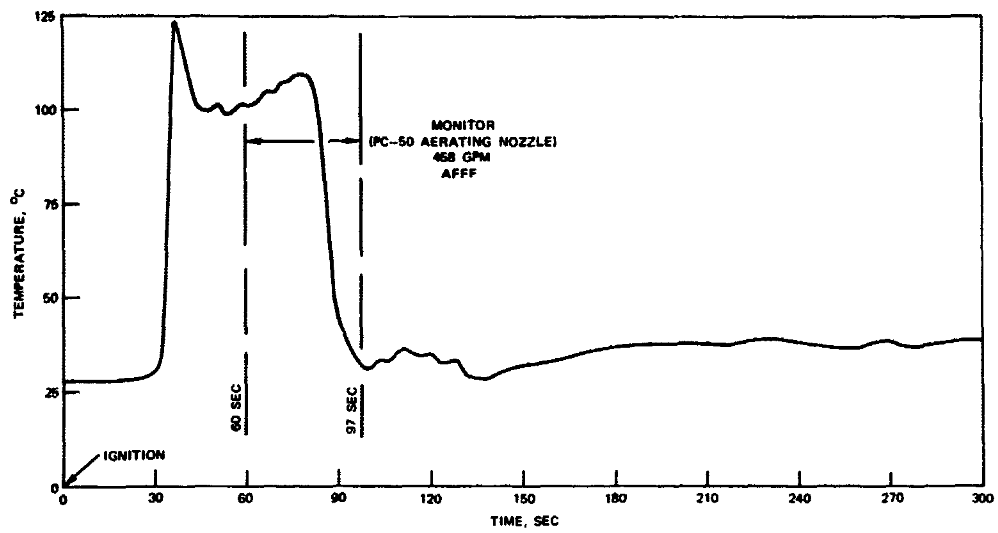
LHL 151759

FIG. 10. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 5.



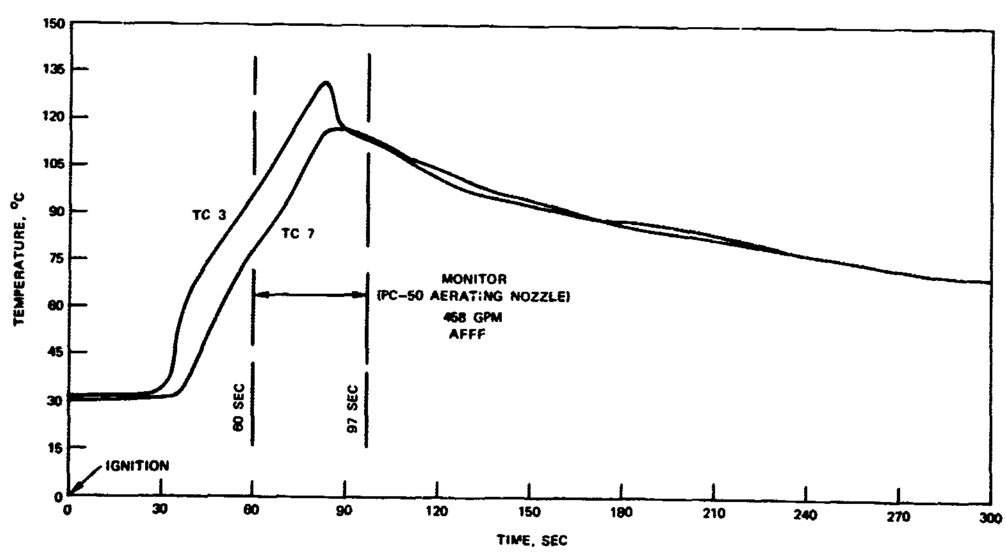
LHL 151760

FIG. 11. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 5.



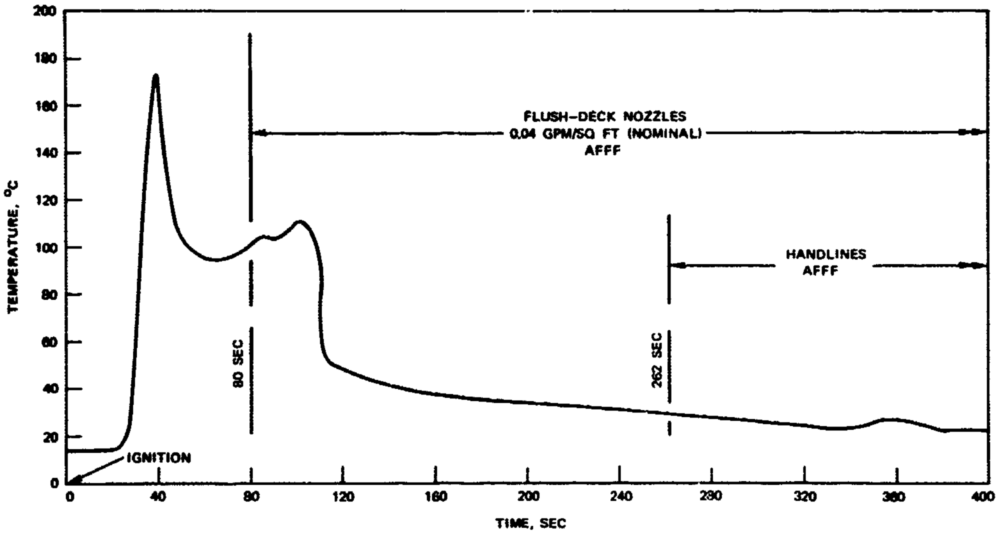
LHL 151761

FIG. 12. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 6.



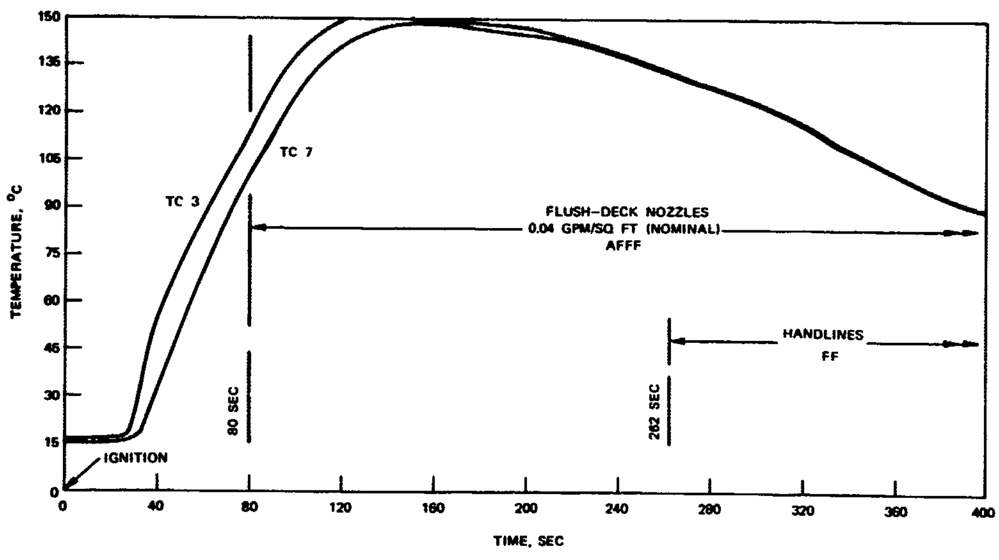
LHL 151762

FIG. 13. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 6.



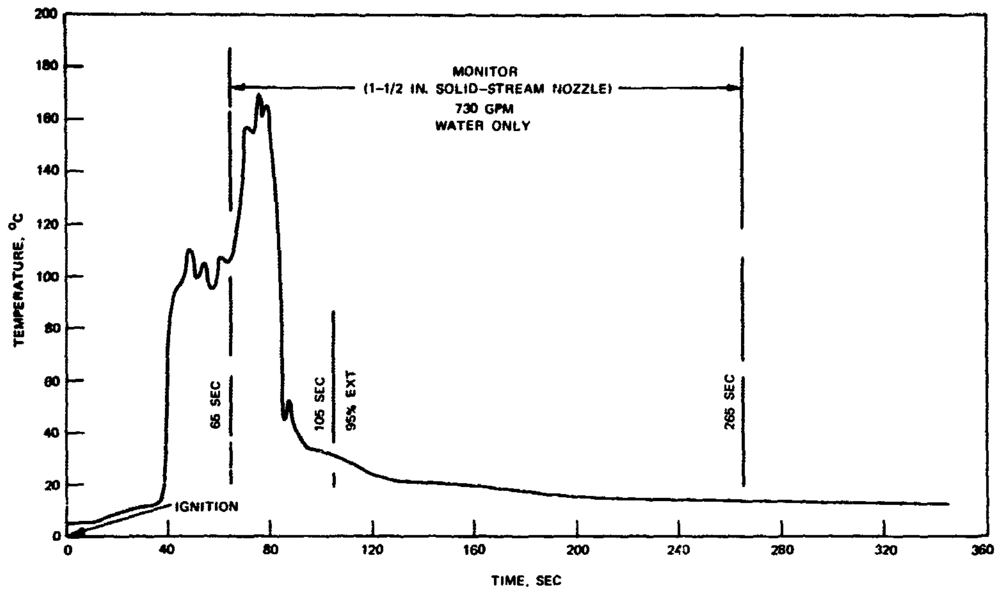
LHL 151763

FIG. 14. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 7.



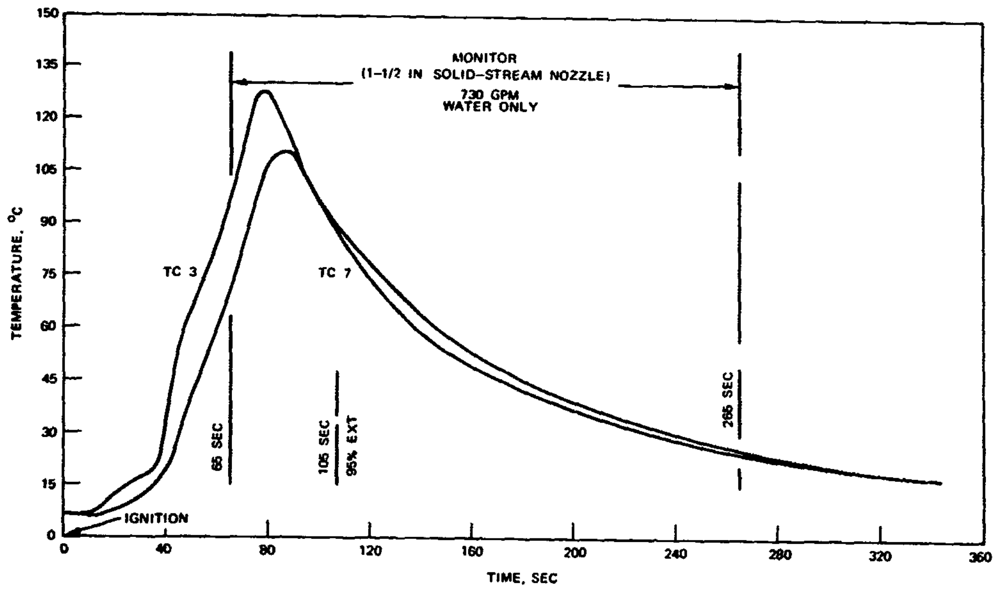
LHL 151764

FIG. 15. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 7.



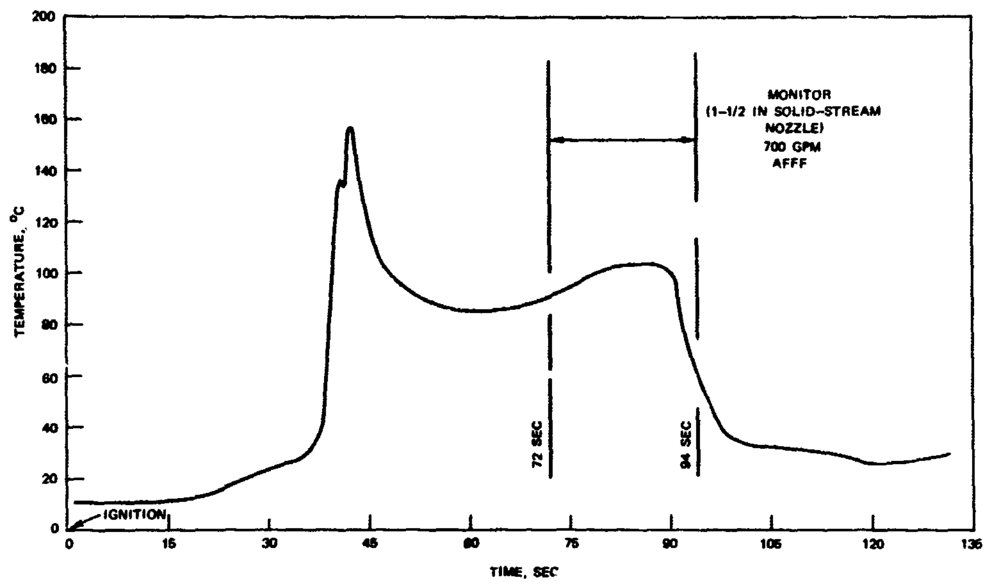
LHL 151765

FIG. 16. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 8.



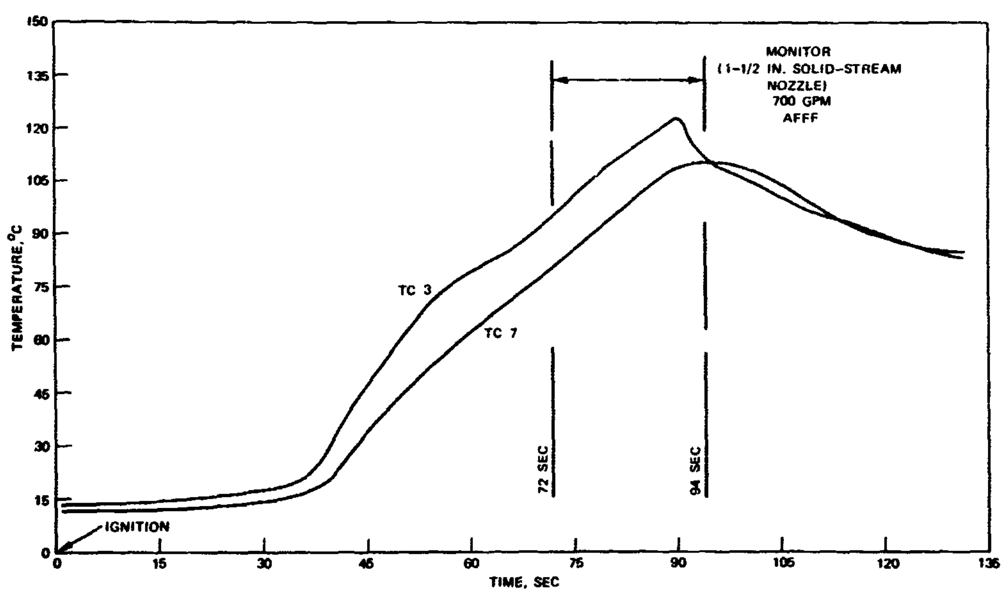
LHL 151766

FIG. 17. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 8.



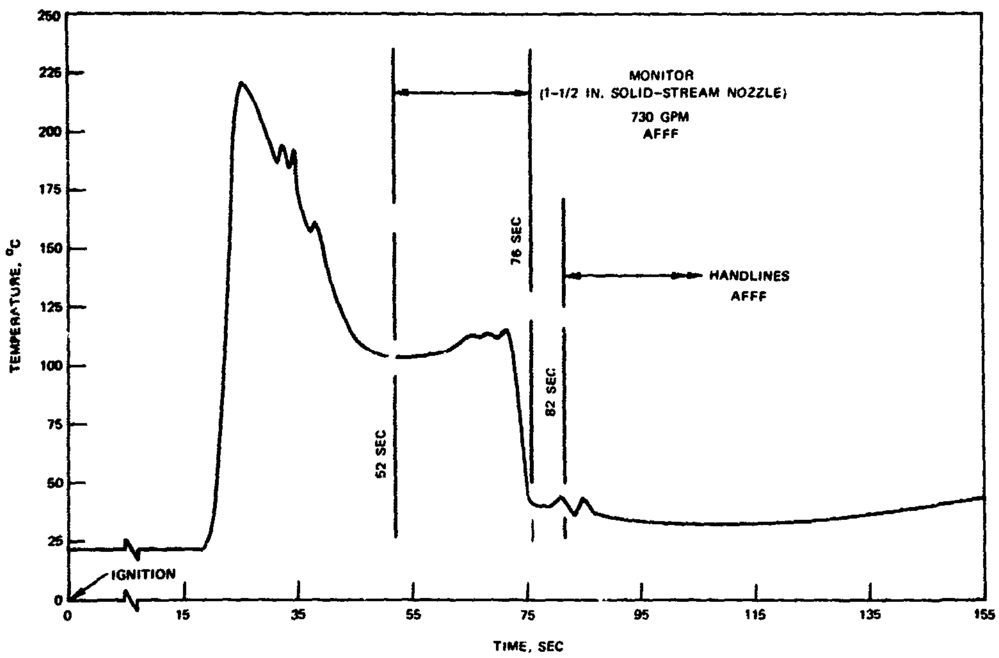
LHL 151767

FIG. 18. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 9.



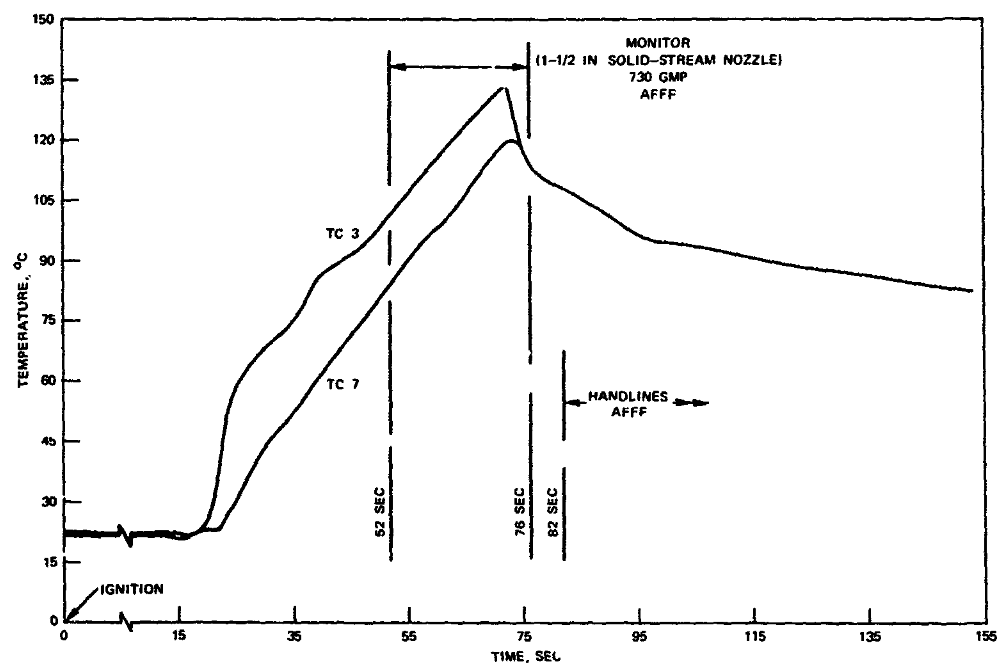
LHL 151768

FIG. 19. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 9.



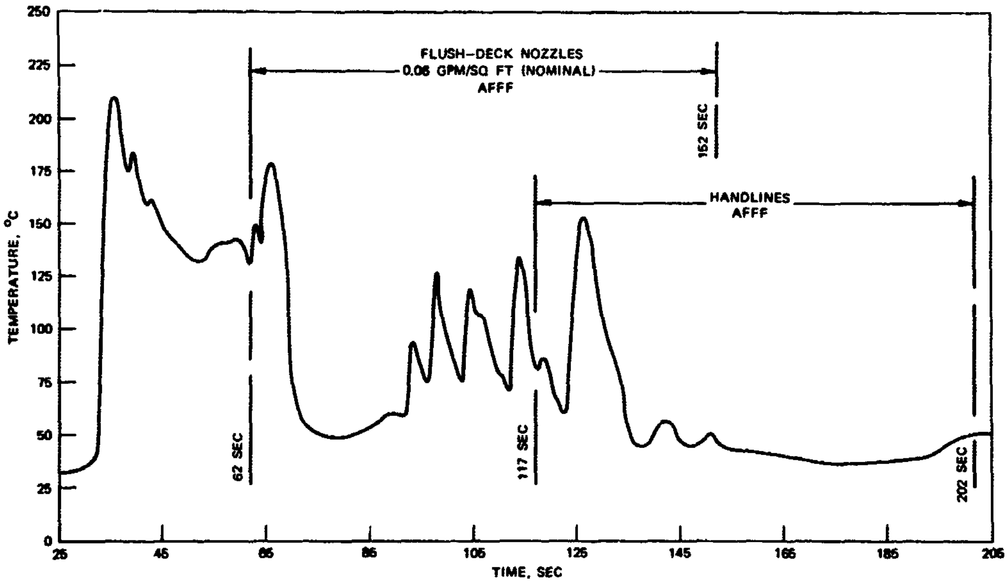
LHL 151769

FIG. 20. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 10.



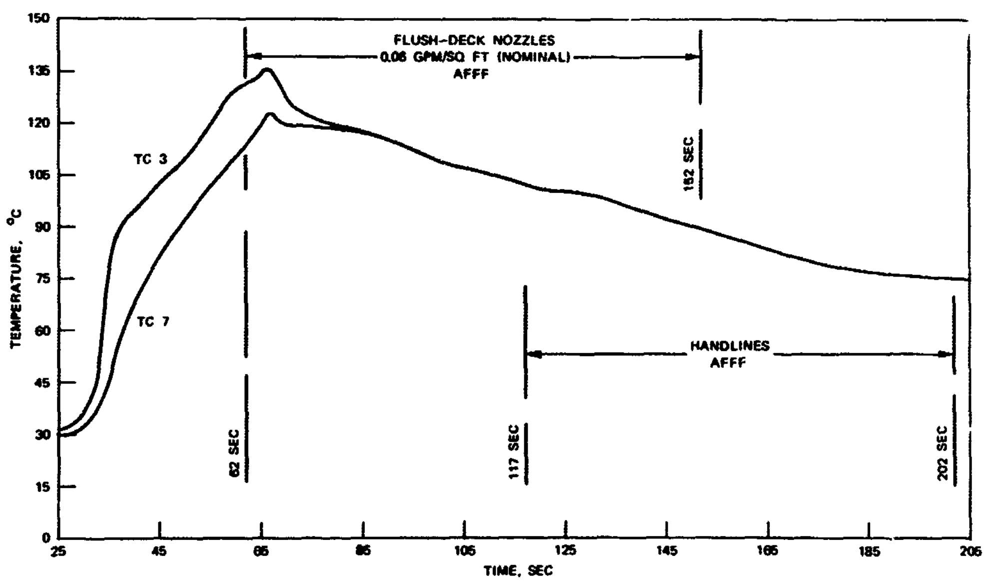
LHL 151770

FIG. 21. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 10.



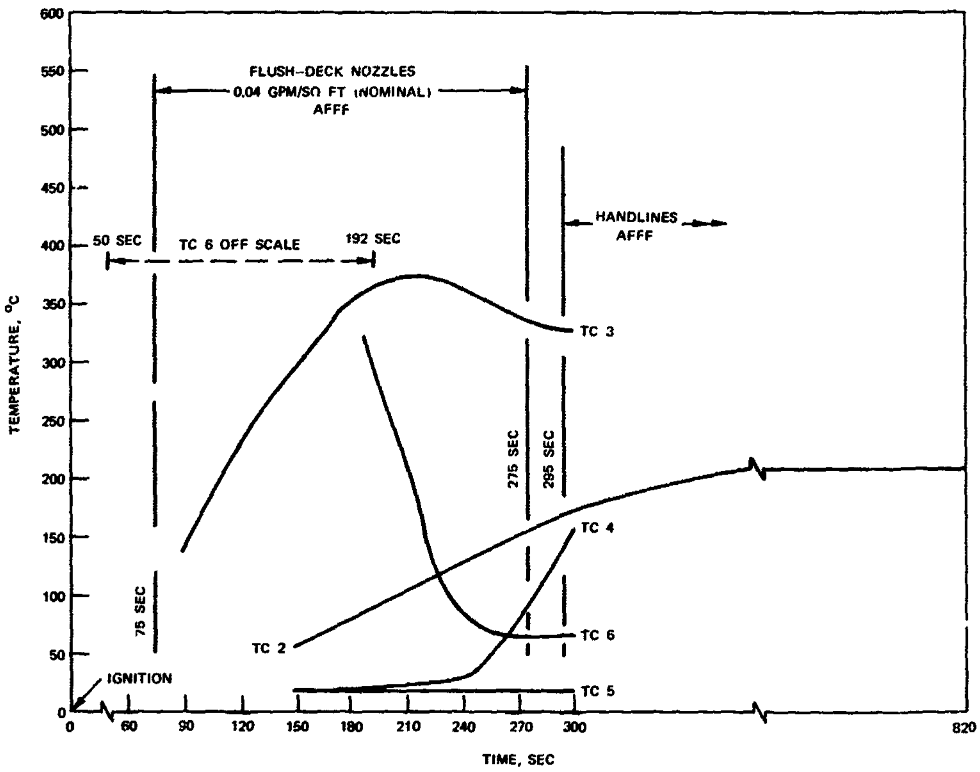
LHL 151771

FIG. 22. Temperature Profile of Flame (TC 9) for Port Mk 82 Bomb During Test No. 11.



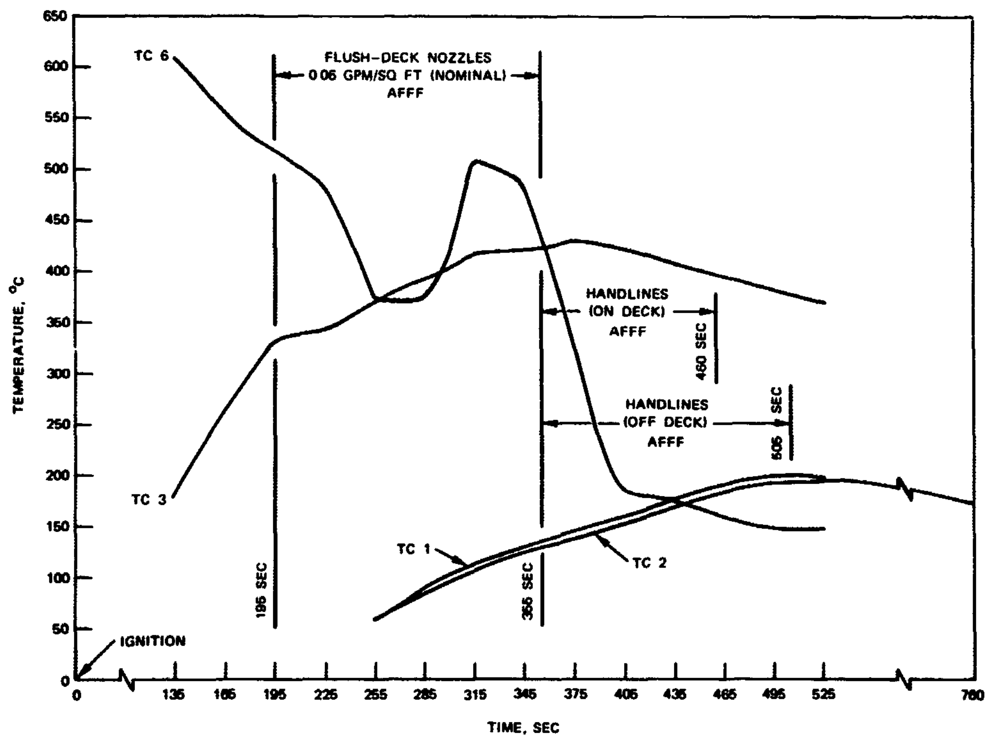
LHL 151772

FIG. 23. Temperature Profiles of TC 3 and 7 for Port Mk 82 Bomb During Test No. 11.



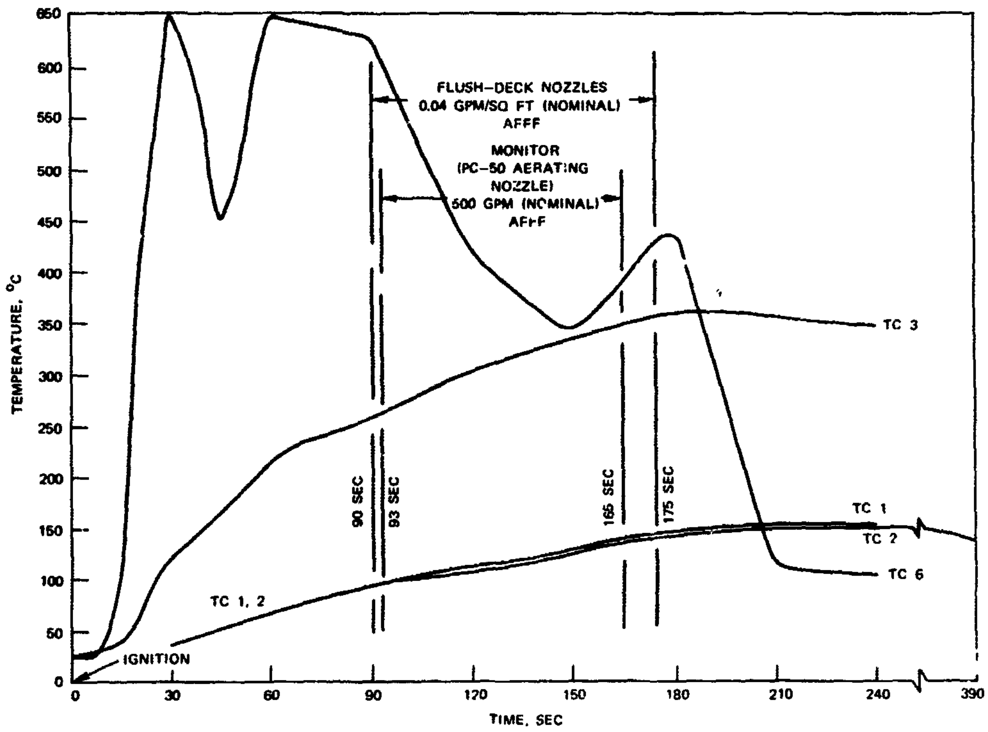
LHL 151773

FIG. 24. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 2.



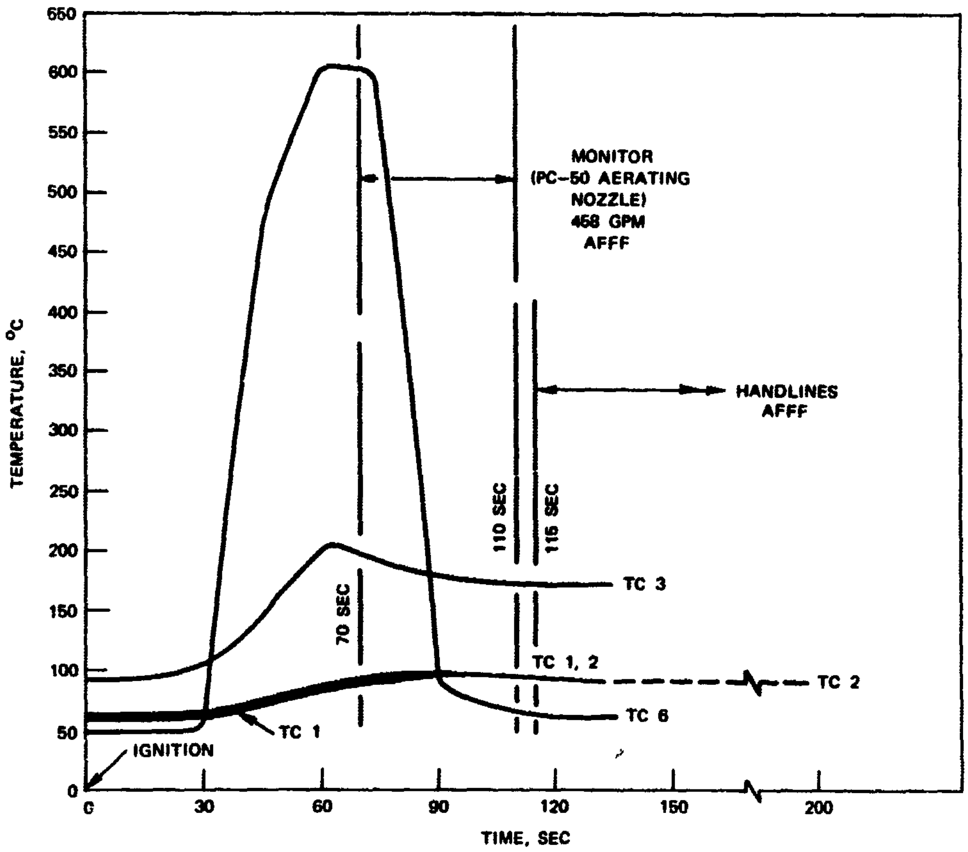
LHL 151774

FIG. 25. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 3.



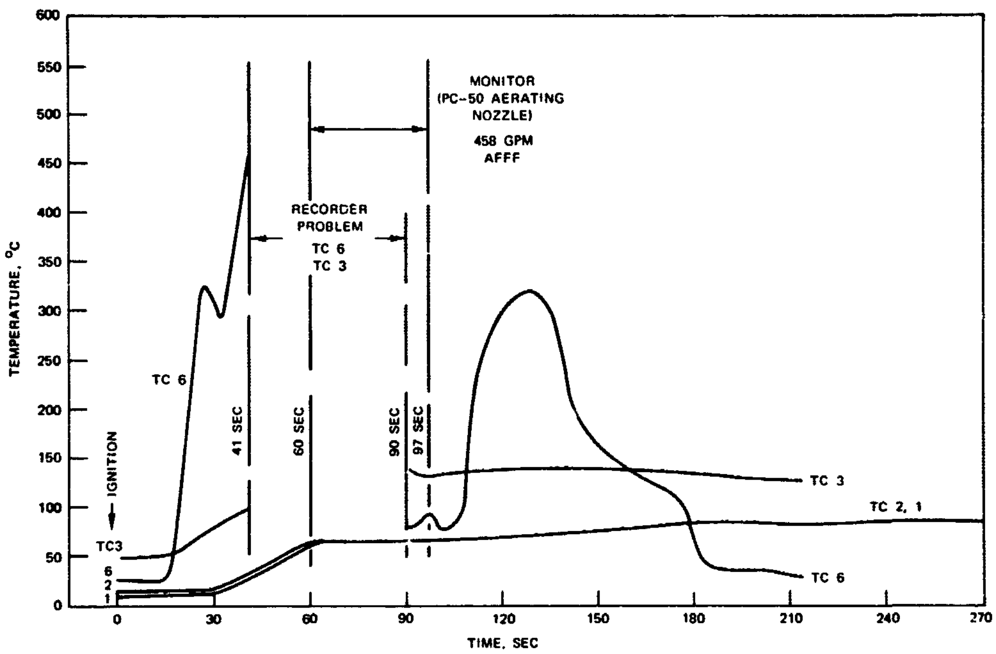
LHL 151775

FIG. 26. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 4.



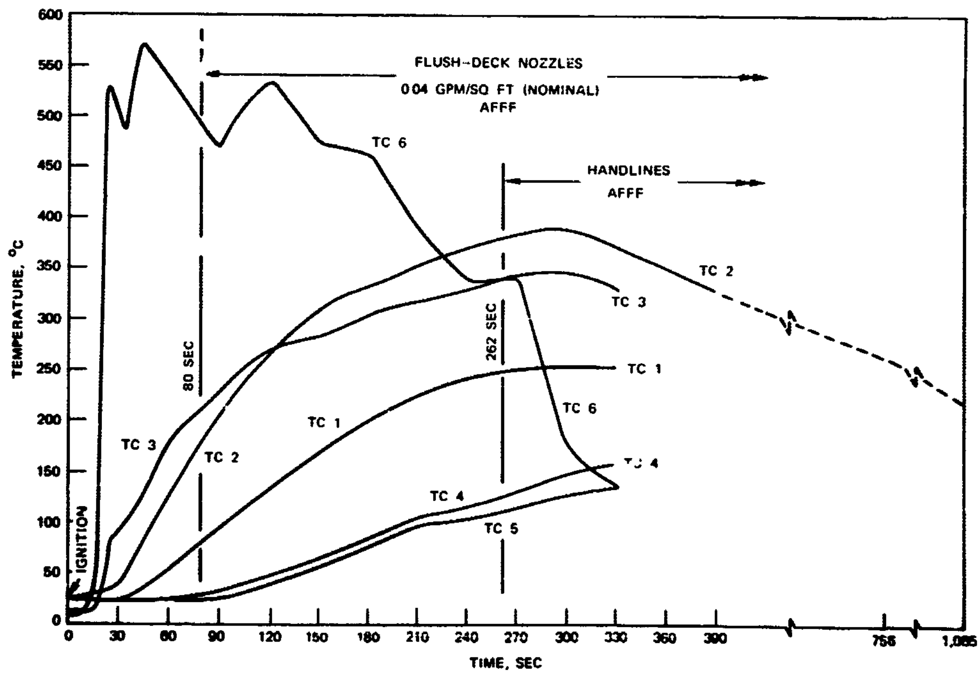
LHL 151776

FIG. 27. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 5.



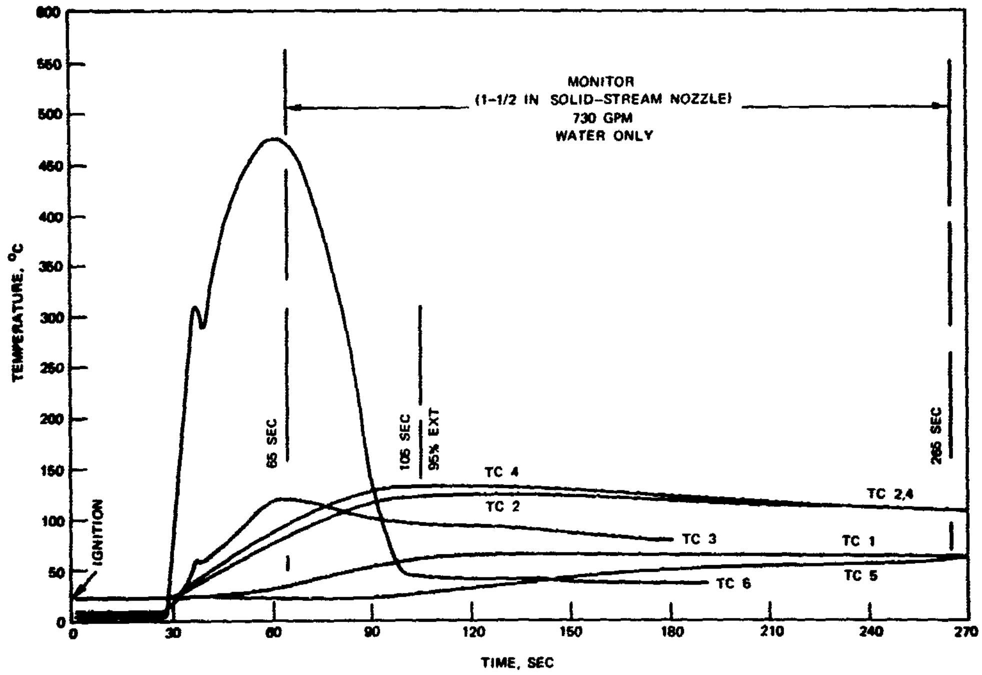
LHL 151777

FIG. 28. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 6.



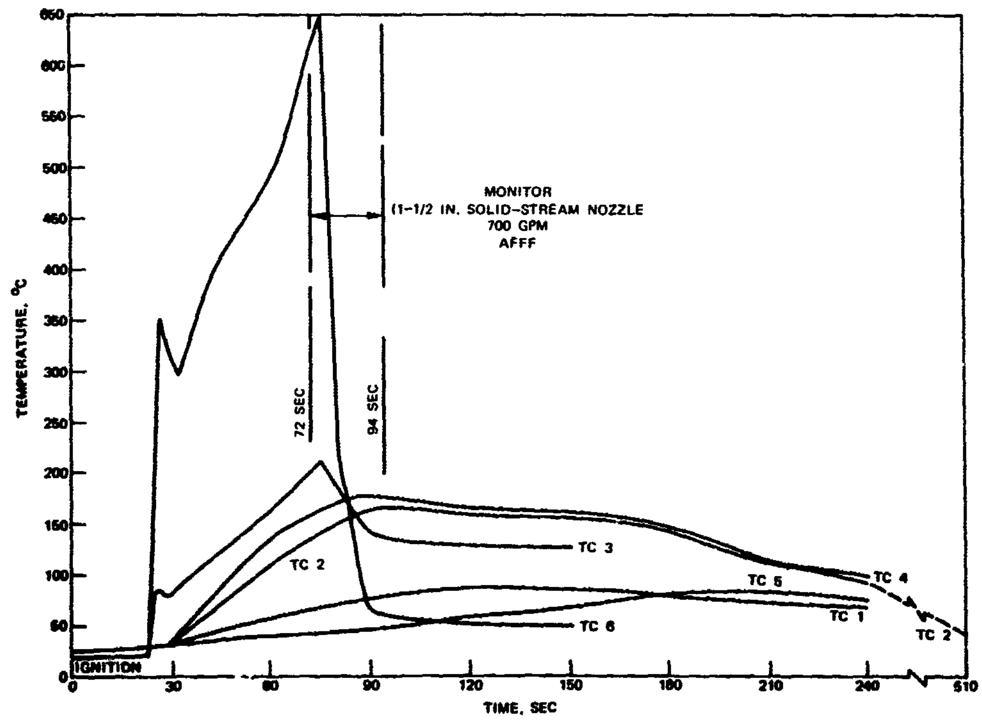
LHL 151778

FIG. 29. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 7.



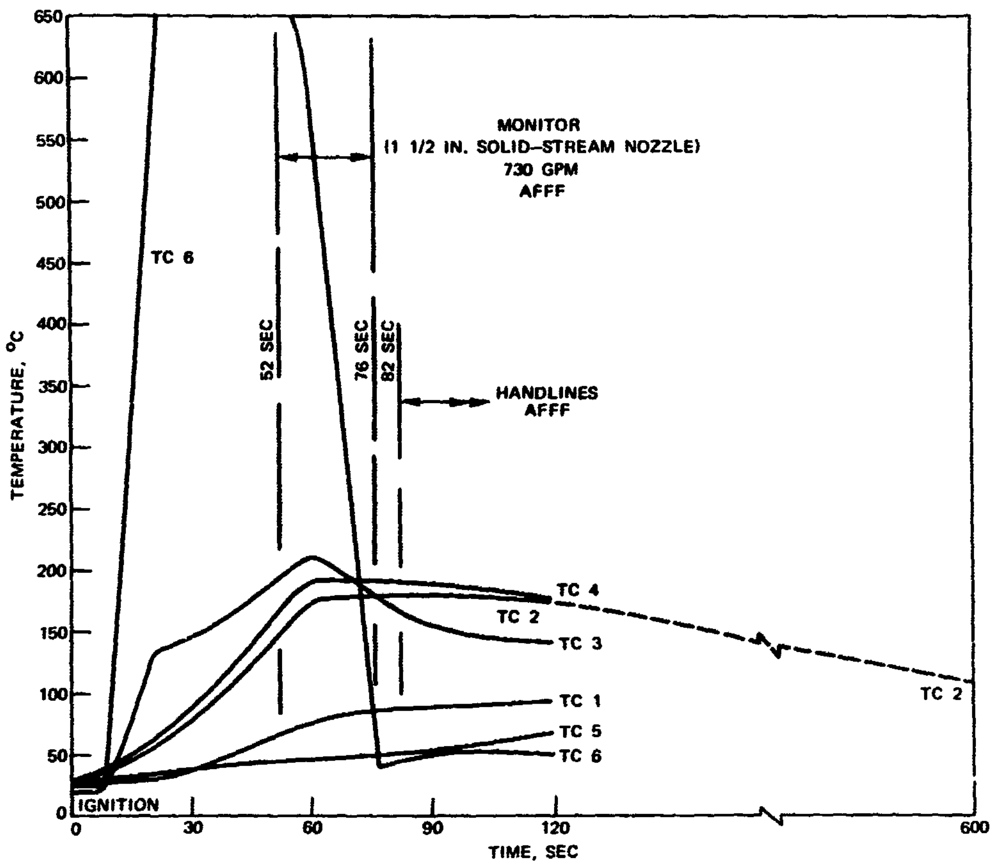
LHL 151779

FIG. 30. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 8.



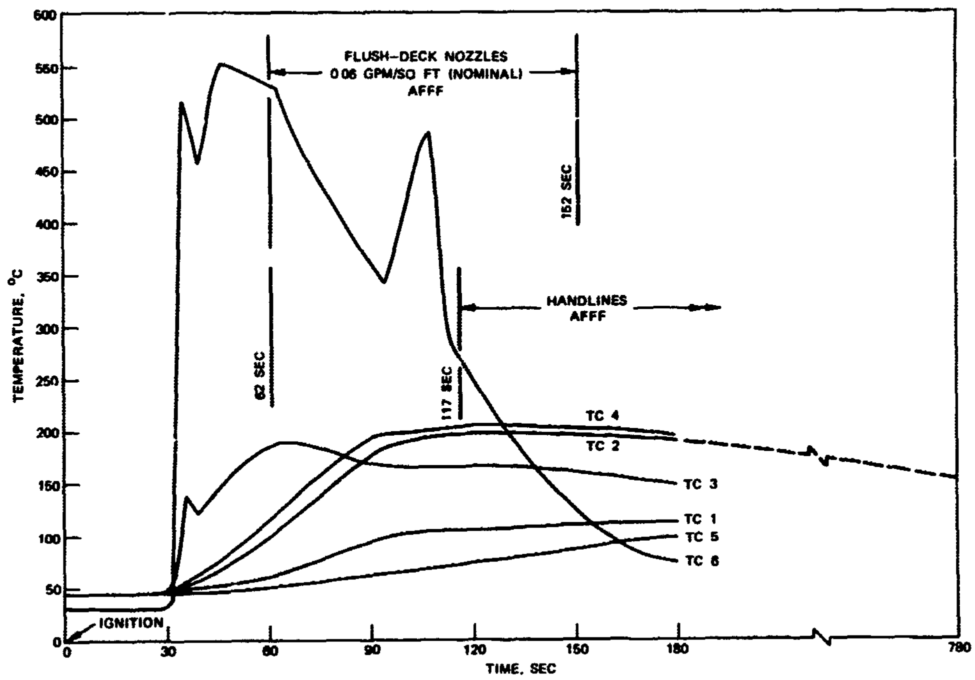
LHL 151780

FIG. 31. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 9.



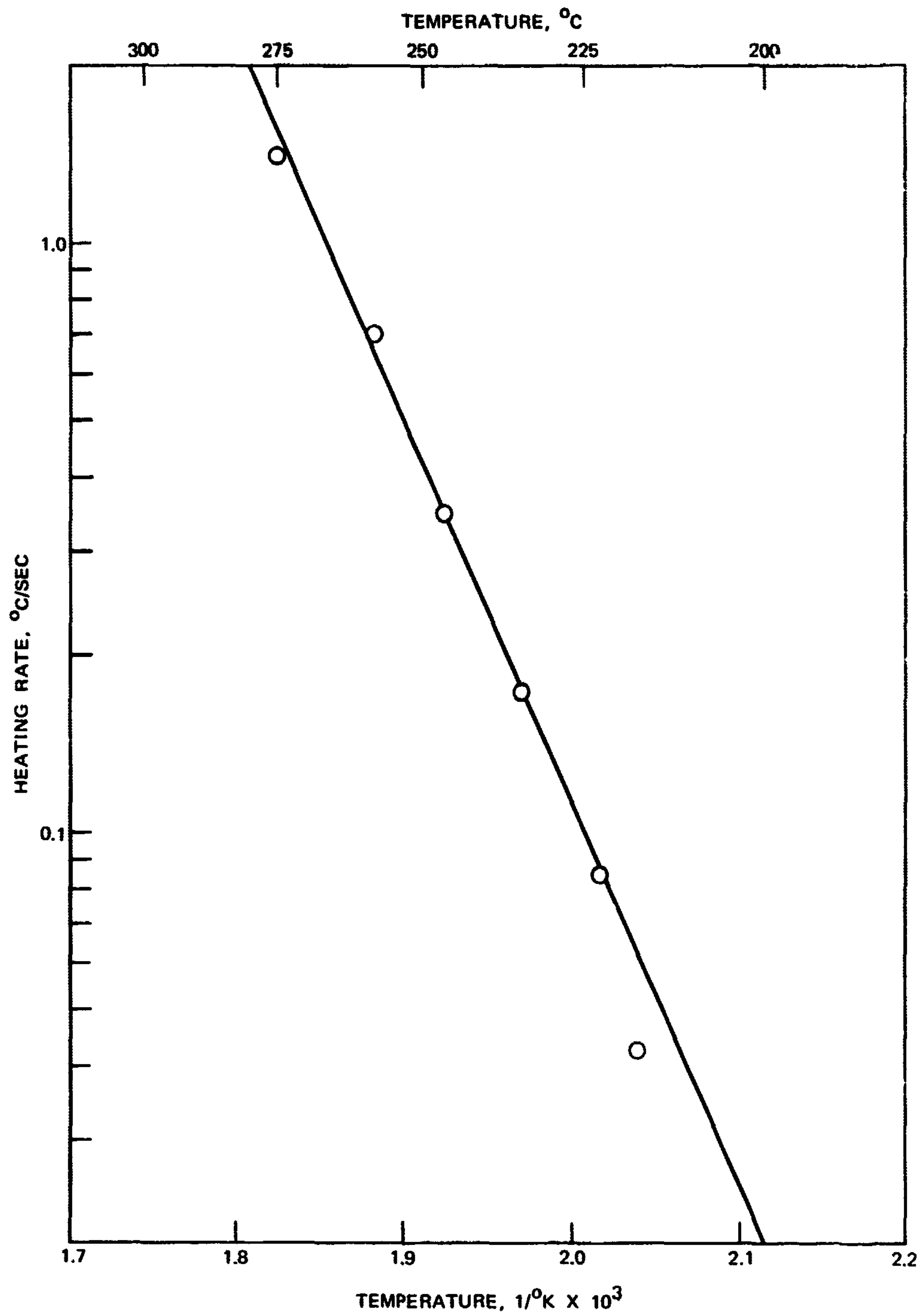
LHL 151781

FIG. 32. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 10.



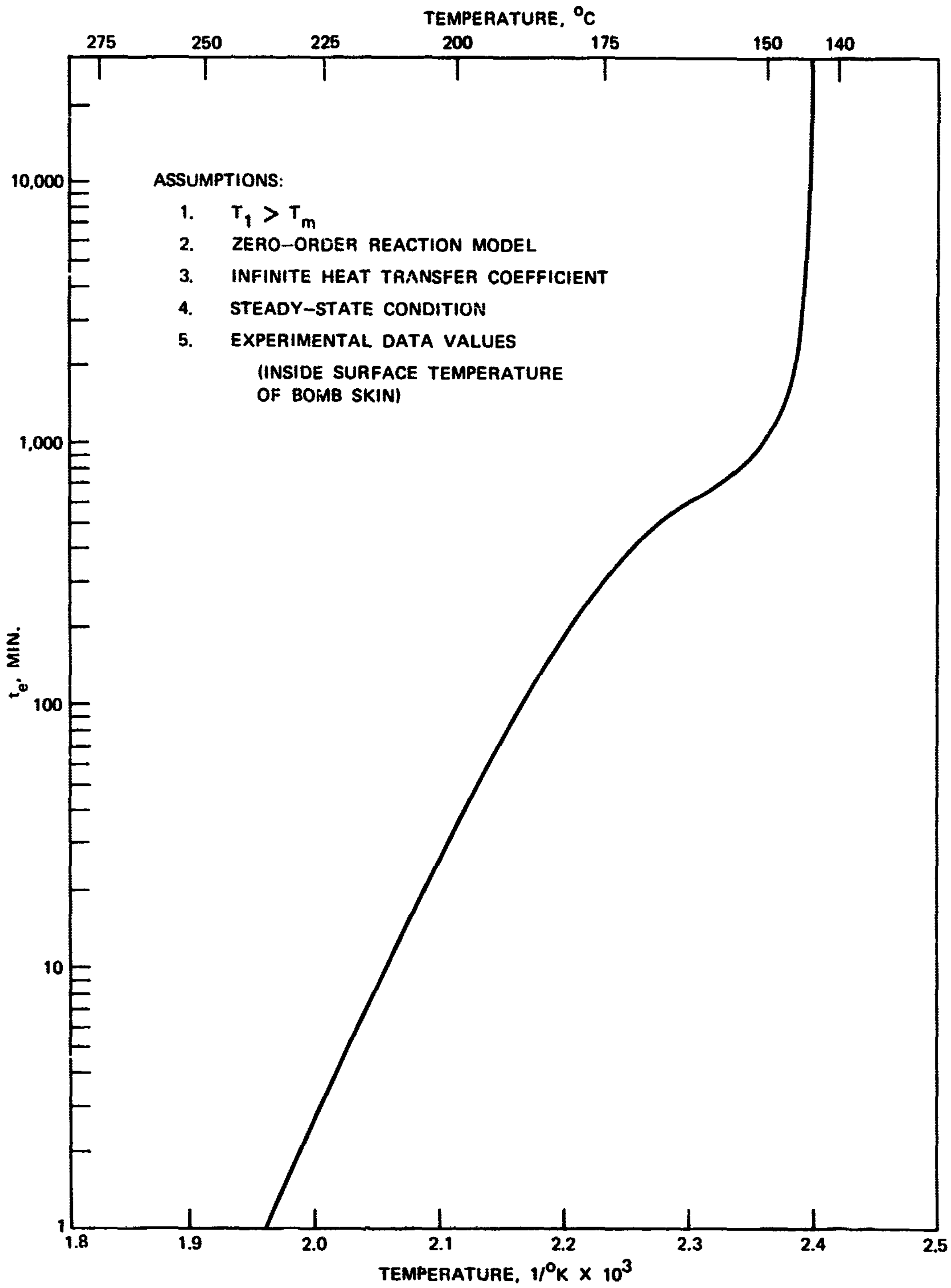
LHL 151782

FIG. 33. Temperature Profiles for Starboard Mk 82 Bomb During Test No. 11.



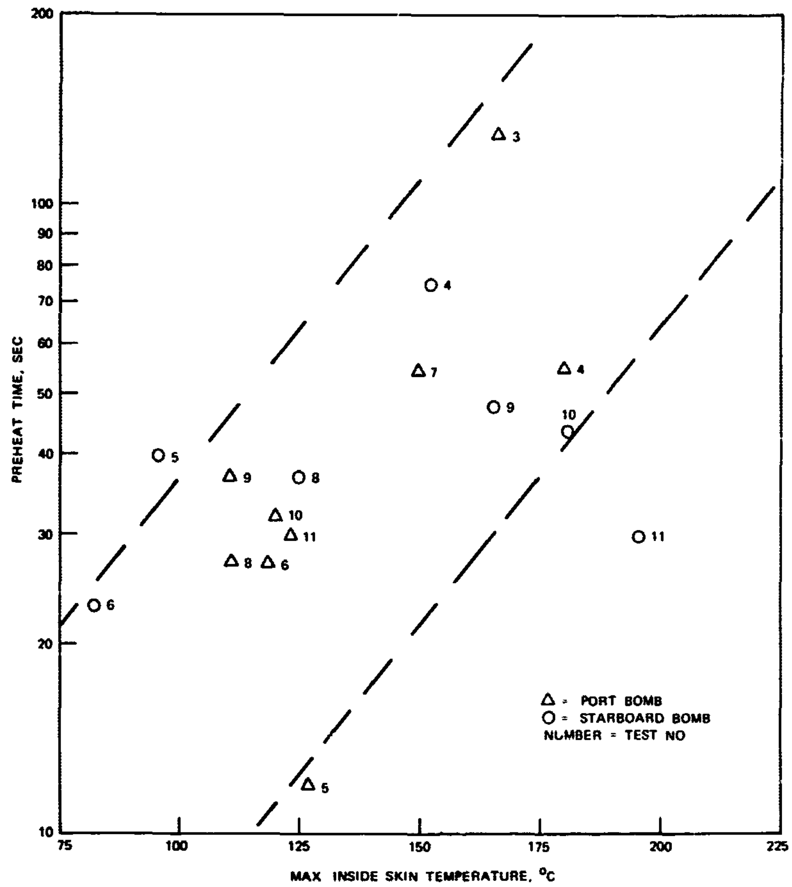
LHL 151783

FIG. 34. DSC Thermal Analysis Data on H-6 Explosive.



LHL 151784

FIG. 35. Predicted Time to Cook-off for H-6 Explosive in a Mk 82 Bomb.



LHL 151785

FIG. 36. Relationship of Bomb Preheat Time to Maximum Inside Skin Temperature.

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13. ABSTRACT

Thermal characteristics were determined on inert Mk 82 bombs subjected to elevated temperatures during the CASS Mini-Deck Test Series Nos. 2 through 11. Theoretical cook-off predictions on the bombs were made on the assumption that the bombs contained H-6 explosive and that the inside and outside surfaces were not insulated or protected in any manner.

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Firefighting						
Mk 82 Bombs						
Cook-off Predictions						

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